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EXPERIMENTAL STUDY OF HEAT TRANSFER ENHANCEMENT FROM DIMPLED TWISTED TAPE IN DOUBLE PIPE HEAT EXCHANGER

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ABSTRACT

The objective of this study is to carry out experimental study of heat transformation and friction factor in a double pipe heat exchanger (DPHE) counter-flow arrangement using twisted tape with dimple inserts. Dimple is one of the types of concavity which enhance the heat exchange with low penalty on lesser pressure. The effect of dimples and protrusions of different diameter and constant diameter to depth ratio on heat conversion and friction factor was researched. This article delivers an evaluation of employing dimpled twisted tape with varying dimple diameters (3 mm, 5 mm and 7 mm) at constant diameter-to-depth ratio (D/H) of the dimples 3 to heat transfer and friction Element characteristics. It's been calculated that the diameter of the dimple is directly proportional to the friction factor (f), consequently, maximum value of f is found at 7 mm diameter. In addition, it's been found that maximum value of Nusselt number (Nu) and performance evaluation criteria (PEC) is found at 5 mm diameter. It is therefore deduced that dimpled twisted tape insert is an effective and economical pathway to enhance heat transfer in heat exchangers.

KEYWORDS: Twisted Tape with Dimple Insert, DPHE, Nu, f & PEC

Original Article

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NOMENCLATURE

"L = length of twisted tape, m"	"l = Tube length of the experimental section, m"
"d = Diameter of inner tube, m"	"T_{hi} = Inlet temperature of hot water, K"
"T_{ho} = outlet temperature of hot water, K"	"T_h = Bulk temperature of hot water, K"
"T_{ci} = Inlet temperature of cold water, K"	"T_{co} = Outlet temperature of cold water, K"
"T_c = Bulk temperature of cold water, K"	"T_w = Average inner tube wall temperature, K"
"U_h = Mean velocity of hot water, m/s"	"Δp = Pressure drop, Pa"
"V_h = Volume flow rate of hot water, m^3/s"	"V_c = Volume flow rate of cold water, m^3/s"
"ρ_{in} = Density of hot water at inlet temperature, kg/m^3"	"ρ_h = Density of hot water at bulk temperature, kg/m^3"
"C_{ph} = sp. heat capacity of hot water, J/kg K"	"C_{pc} = sp. heat capacity of cold water, J/kg K"
"ν = kinematic viscosity of hot water, m^2/s"	"K_h = Thermal conductivity of hot water, W/Mk"
"A = Surface area of inner tube, m^2"	"h_i = Heat transfer coefficient, W/m^2K"
"Q_h = Heat transfer rate released by hot water, W"	"Q_c = Heat transfer rate absorbed by cold water, W"
"Q = Mean heat transfer rate, W"	"Re = Reynolds number"
"D = Dimple diameter, m"	"f = Friction factor"
"H=Depth of dimple, m"	"Nu =Nusselt number"
"PEC =Performance evaluation criteria"	

1. INTRODUCTION

Heat transfer is an inevitable phenomenon and is employed in a number of applications such as refrigeration, air-conditioning, thermal power plants, food processing, feedstock processing, etc. In order to transfer the heat with lesser wastage and more efficiency, heat exchangers are used. The performance of a “double pipe heat exchanger” is vital vis-à-vis system economics and efficiency. Consequently, it is significant to improve heat transfer to acquire sustainable energy growth. Thus, studies on heat transfer augmentation have been impressively attracting investigators consideration in past several years. Various researchers have worked on heat transfer enhancement by using different inserts of geometry which produces secondary motion of flowing fluid and enhances heat transfer.

Basically, Heat transfer enhancement pathways are of three types, namely, active method, passive method and compound method [1]. In first method, external power or energy has been supplied to improve heat transfer, such as induced pulsation by cams and reciprocating plungers, mechanical aids, fluid vibration, surface vibration, application of electrostatic fields, application of magnetic field to disturb the seeded light particles in a flow stream, etc. [2]. On the other hand, passive method employs geometrical or surface alterations in the flow channel. These modifications are carried out by inducing inserts or supplementary devices. Swirl flow devices, extended surfaces, treated surfaces, rough surfaces; coiled tubes, surface tension devices, etc. are used in passive heat transfer enhancement pathway [3-6]. The combination of active and passive methods is called as compound method (e.g. rough surface with fluid vibration).

Passive method is the most popularly used method as it employs no external power and enhance the heat transfer rate to a significant extent. Therefore, an optimal heat transfer rate is obtained at economical pumping power. Tube inserts technique is commonly used as one of the routes under passive method. Few examples of tube inserts in a heat exchanger are twisted tape, helical spring, ribs, conical nozzle, conical ring, etc. [1, 4]. Among all the commonly used tube inserts, twisted tape insert is considered as a primary choice and therefore extensively studied and researched by numerous researchers [7-29] worldwide.

Since 1960s, a vast number of theoretical and experimental studies are applied to calculate the performance of a heat exchanger with wide variety of twisted tapes [1]. Twisted tapes can be manufactured in numerous designs such as typical, perforated, notched, jagged, center-cleared, V-cut, serrated, square cut, helical screw, etc. using different techniques as shown in Table 1.

Table 1: Schematic Geometry of Different Configurations of Twisted Tape [1, 7, 12]

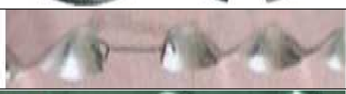
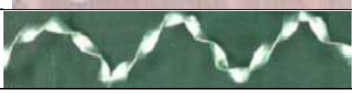
Name	Configuration
Conventional TT	
Triangular groove TT	
Semicircular groove TT	
Regularly spaced TT	
Helical TT	

Table 1: Contd.,

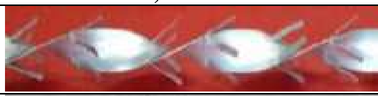
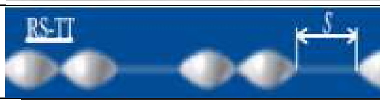
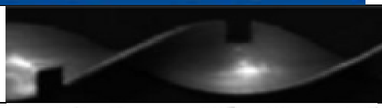
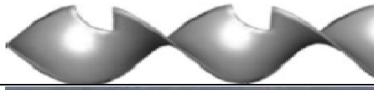
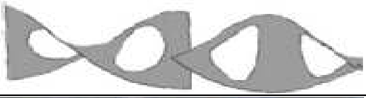
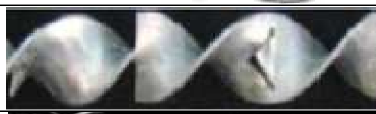
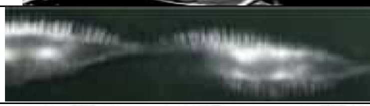
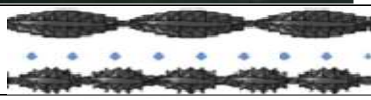
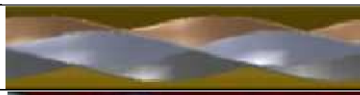
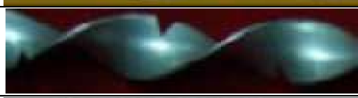
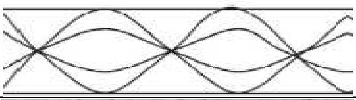
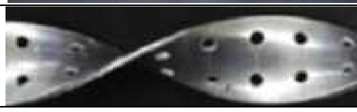
TT with V-winglet	
Helical screw tape	
Regularly spaced TT	
Square cut TT	
Elliptic cut TT	
Peripherally cut TT with an alternate axis	
Staggered TT with center holes	
TT consisting of center wings and alternate axes	
TT with circular rings	
Serrated TT	
Ribbed spiky TT	
TT with alternate axes	
Triple TT	
V-cut TT	
Double TT	
Center cleared TT	
TT with geometrical progression ratio	
TT with wire nails	
Perforated helical TT	

Table 1: Contd.,	
Jagged TT	
Notched TT	
Perforated TT	
Left-right TT	

Dimple is one of the types of concavity which increase the heat transfer with lesser pressure drop. Terekhov et al. [30] performed the experimental investigation using single dimple on the heat transfer and frictional resistance (D/H = 2-7.69, Re = 10000-70000). Yadav [31] assessed the impact of half-length twisted tapes on a U-bend double pipe heat exchanger on heat transfer and pressure drop. A 40% increase in the heat transfer was reported with the inserts vis-à-vis without inserts. However, the performance evaluation criterion of a smooth tube was reported to be 1.3 to 1.5 times higher than the modified heat exchanger. Furthermore, Naphon [32] carried out the experimental investigation on a double pipe heat exchanger with and without insert to assess the variation in heat transfer and pressure drop. The thickness of the inserts was 1 mm and made up of aluminum. Hot and cold water was employed as the working fluid. They reported a vital improvement in heat transport and a rise in pressure drop from the heat exchanger with tape folds compared to without inserts.

Mwesigye A.et al., [33] carried out numerical work to evaluate the performance of conventional twisted tape inserts in a heat exchanger. They employed finite volume method. The Reynolds number of the flow was from 10260 to 1353000. The twist ratios were taken from 0.5 to 2 whereas width ratio was taken from 0.53 to 0.91. The results reported an increase of about 169% in heat transfer, a decrease in absorber's tube temperature difference along circumference up to 68% and an enhancement in thermal PEC up to 10% over a receiver within a plain absorber tube. In addition, they reported an optimal Re to have a direct relation with twist ratio and inverse relation with width ratio. They also found maximum decrease in entropy generation rate to be 58%.

After a thorough literature review, it has been concluded that numerous researchers have investigated different types of twisted tape inserts in their experimental and modeling studies. However, no experimental study has so far been done on the assessment of heat transfer by using twisted tape with dimple insert in a double pipe heat exchanger. The objective of this work is to study the heat transfer and friction characteristics in a horizontal double pipe heat exchanger using twisted tape with dimple inserts of different dimple diameters at constant dimple diameter (D) to dimple depth (H) ratio. In the present work, the effect of dimple diameter on heat transfer and pressure drop is experimentally analyzed. The Reynolds number ranges from 6000 to 14000 with hot/cold water as the working fluid. The result of heat transfer enhancement and pressure drop obtained experimentally have been analyzed and thoroughly discussed.

2. EXPERIMENTAL SET-UP

The schematic of the heat exchanger system employed for the experimental work is depicted in figure.1.

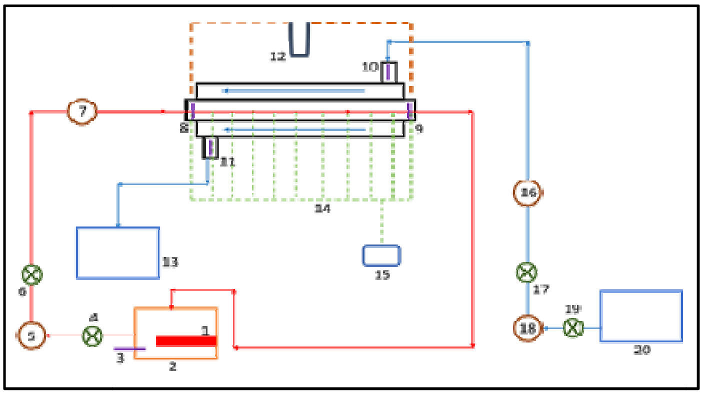


Figure 1: Schematic of the Experimental Set-up.

"1. Heater, 2. Hot water tank 3. RTD-hot water in tank 4. Ball valve 5. Hot water pump 6. Hot water control valve 7. Flow meter 8. RTD-Hot water inlet 9. RTD-Hot water outlet 10. RTD-cold water inlet 11. RTD-Cold water outlet 12. U-Tube manometer 13. Cold water recover 14. Thermocouples 15. Data logger 16. Flow meter 17. Cold water control valve 18. Cold water pump 19. Ball valve and 20. Cold water tank".

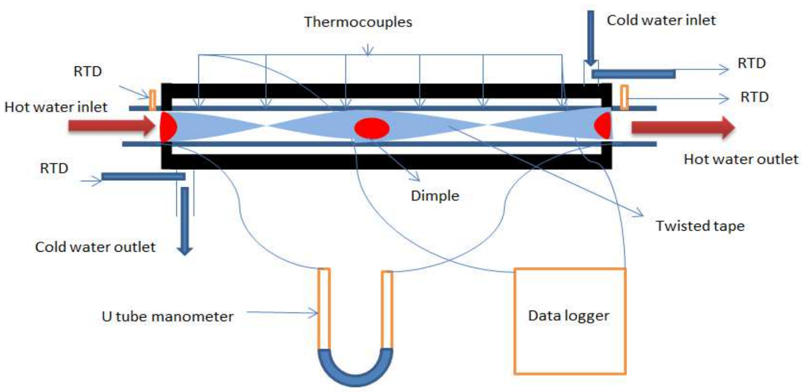


Figure 2: Pictorial View of Test Section.

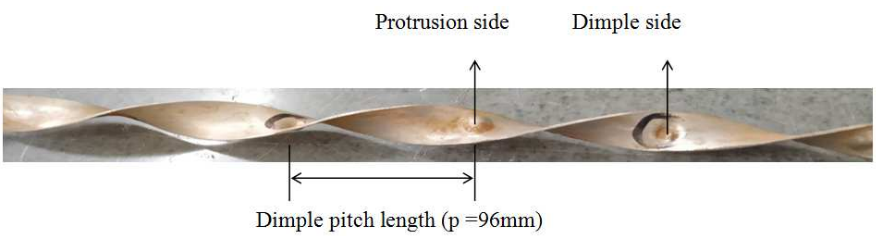


Figure 3(a): Details of Twisted Tape with Dimples used in Experimental Work.

Figure 3(b): The Twisted Tape without Dimples used in Experimental Work.

Figure 3(c): The Twisted Tape with Dimples Diameter 7mm used in Experimental Work.

Figure 3(d): The Twisted Tape with Dimples Diameter 5mm used in Experimental Work.

Figure 3(e): The Twisted Tape with Dimples Diameter 3mm used in Experimental Work.

The experimental setup consisted of a double pipe heat exchanger using water as the liquid. Hot water circulates throughout the inner tube whereas chilly water flowed through the annulus. Hot water route consisted of warm water storage tank armed with electric heater along with rheostat, 0.5 HP centrifugal pumps, a rotameter and a piping structure with appropriate valves. These hot water pipes and storage tank have been coated with proper insulation depth. Cold water route consisted of a 0.5 HP centrifugal pump, a rotameter and a piping structure with valves. Length of internal tubing was 2 mm diameter, internal diameter of 16 mm and length of 2.4 m whereas depth of outer tubing was 3 mm diameter, internal diameter 30 mm and length of 2.4 m. The inlet temperature of warm water was kept in 70 °C whereas inlet temperatures of cold water has been in the room temperature (30-32°C). Six T-type calibrated thermo couples using a measurement error of 0.1 °C were put over the outer surface of the tube to assess the surface temperature. The inlet and outlet temperature of hot and cold water have been listed with thermal resistances using a measurement error of 0.1 °C. Stress drop of warm water flowing in evaluation piece were quantified by U-tube manometer. The worth of temperature, pressure drop and flow rate were listed for improvement once the system reached steady state condition.

Twisted tapes used for the study are made of aluminium of thickness 1 mm and twist ratio of 5.5 for all the cases. The effectiveness of the proposed twisted tape inserts with dimples, in achieving the enhanced rate of heat transfer, has been evaluated on the basis of outlet temperature, surface temperature of inner tube and pressure drop. The variations in the physical properties of the twisted tape with dimples of different diameter, namely, 3 mm, 5 mm and 7 mm with D/H ratios of 3.0, have been made at the constant twist ratio of 5.5. The Reynolds Number of the warm liquid flow through the tube inner was varied from 6000 to 14000. The selection of the range of Reynolds numbers was done depending on the average inlet rate and tubing hydraulic diameter. The construction diagram of used jagged tapes is displayed at Figure 3.

3. DATA REDUCTION

It is desirable to understand some parameters related to the geometry and performance assessment.

- **Twist Ratio**- “It is defined as the ratio of the distance between two points which are on the same plane measured parallel to the axis of a twisted tape (i.e. half length of the twist pitch) to the inside diameter of the tube. It is usually denoted by TR or y”.

  Numerically, TR= $\frac{\left(\frac{P}{2}\right)}{D}$

- **Reynolds Number**- “It is the ratio of the product of tube side hydraulic diameter, mean fluid velocity of the tube and density to the dynamic viscosity of the fluid. It is denoted by Re”.

  Numerically, Re = $\frac{dU\rho}{\mu}$

- **Nusselt Number**- "It is denoted by Nu and is the ratio of the product of convective heat transfer coefficient and the tube side hydraulic diameter to the thermal conductivity".

  Numerically, Nu = $\frac{hd}{k}$

- **Friction Factor**- "It is the ratio of twice the product of pressure drop in the whole tube and tube side hydraulic diameter to the product of density, characteristic linear dimension and the square of mean fluid velocity of the tube. It is denoted by f".

  Numerically, f = $\frac{\Delta p}{\left(\frac{\rho_h U_h^2}{2}\right)}\left(\frac{L}{d}\right)$

- **Thermal Performance Factor**- "It is denoted by η or PEC and it is the ratio Nusselt Numbers (Nusselt Number of the tube with twisted tape to the Nusselt Number of the plain tube) to cube root of the friction factors (friction factor of the tube with twisted tape to the friction factor of the plain tube) under constant pumping power".

  Numerically, PEC=$\frac{\left(\frac{Nu}{Nu_o}\right)}{\left(\frac{f}{f_o}\right)^{0.33}}$

The typical value of in and out temperature is regarded as the majorities mean temperature for warm and chilled water. Several formulae utilized in the current work are represented in Eq. (1) to Eq. (11).

Combined temperature of warm liquid

$$T_h = \frac{(T_{hi} + T_{ho})}{2} \quad (1)$$

Combined temperature of chilled liquid,

$$T_c = \frac{(Tci + Tco)}{2} \quad (2)$$

Typical temperature of wall

$$T_w = \frac{T_1+T_2+T_3+T_4+T_5+T_6}{6} \quad (3)$$

Mean velocity of warm liquid

$$U_h = \frac{(V_h \times \rho_{in})}{\left(\frac{3.14 d^2 \times \rho_h}{4}\right)} \quad (4)$$

Reynolds Number (for warm liquid)

$$Re = \frac{U_h \times d}{\nu} \quad (5)$$

Heat exchange rate released by warm liquid

$$Q_h = \rho_h \times V_h \times C_{ph}(T_{hi}-T_{ho}) \quad (6)$$

Heat exchange rate absorbed by chilled liquid

$$Q_c = \rho_c \times V_c \times C_{pc}(T_{co}-T_{ci}) \quad (7)$$

Mean value of the heat exchange rate

$$Q = \frac{(Qh + Qc)}{2} = h_i \text{ x } A \text{ x } (T_h\text{-}T_w) \quad (8)$$

Nusselt Number

$$Nu = \frac{(hi \text{ x } d)}{Kh} \quad (9)$$

Friction factor

$$f = \frac{\Delta p}{\left(\frac{\rho_h U_h^2}{2}\right)} \left(\frac{L}{d}\right) \quad (10)$$

$$PEC = \frac{\left(\frac{Nu}{Nuo}\right)}{\left(\frac{f}{fo}\right)^{0.33}} \quad (11)$$

4. RESULTS AND DISCUSSIONS

4.1 Validation of Plain Tube without Twisted Tape Inserts

Experimental set-up is validated against the standard correlations (Eq. 12 and 13) suggested by the researchers [34] to justify the heat transfer data obtained through the experimentation.

The numerical values of Nu and f in the experiments of plain tube were compared to the Gnielinski and Filonenko correlations, respectively. The results reveal that the experimental values are within the permissible limits. The maximum deviation found is ±7% for Nusselt number and 7.5% for friction factor.

Gnielinski Correlation

$$N_{uf} = \frac{\left(\frac{f}{8}\right)(\text{Re} - 1000)\text{ Prf}}{\left(1+12.7\left(\frac{f}{8}\right)^{0.5}(P_r)^{0.66}-1\right)\left(1+\left(\frac{d}{L}\right)^{0.66}\right)C_1} \quad (12)$$

For liquid, $C_1 = \frac{\text{Prf}}{\text{Prw}} = 0.01$

If $\frac{\text{Prf}}{\text{Prw}} = 0.05$ to 20

Filonenko Correlation

$$f = (1.82 \log \text{Re} - 1.64)^{-2} \quad (13)$$

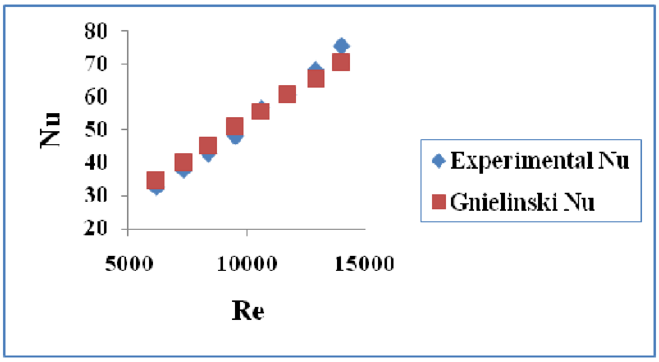


Figure 4: Comparison of the Experimental Nu and Theoretical Nu for the Plain Tube.

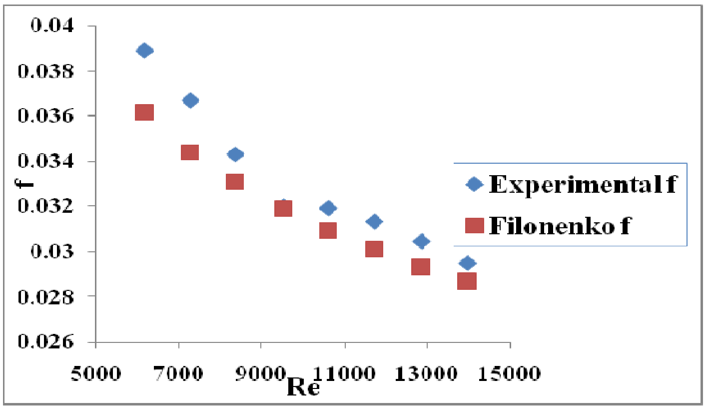


Figure 5: Comparison of the Experimental f and Theoretical f for the Plain Tube.

4.2 Effect of Dimple Diameter on Heat Transfer

The heat transfer and friction features of plain tube, twisted tape with no dimples and groove tape using dimples (D=3mm,5mm and 7mm) are provided in figure 7 and 6 respectively; in which the consequences of dimple on heat transport enactment and frictional resistance are mostly considered. It may be observed that in most of the instances Nusselt number rises with a rising Reynolds number. When paired to a plain tube, jagged tape with no dimples and also dimples really enhances heat transport. For the explored range of Re, Nu from the tube using jagged tape with no dimple and also dimples of diameter 3mm, 5mm and 7mm has been 1.09-1.24, respectively 1.21-1.52, and 1.50-1.82 along with 1.26-1.65 times respectively greater than the plain tube. Nusselt number ratio declines with increase in Reynolds number, it means twisted tape provides better effect for reduced value of Re (weak turbulence). It had been discovered that the Nusselt number is best for dimple diameter 5mm and It's 1.19- 1.24, 1.10-1.18 along with 1.37-1.46 times more compared to twisted tape with dimple diameter 3mm, 7mm and twisted tape without dimple respectively. The Nusselt number increases from dimple diameter 3mm to 5mm and it decreases from 5mm to 7mm of dimple diameter. Since dimples separates the fluid flow from the tape at the leading edge and reattached it at the trailing edge and there is a vortices generated inside the dimple from 3mm to 5mm diameter which enhances the tube wall temperature and hence heat transfer increases but from 5mm to 7mm there is some flow that trapped at the bottom of the dimple and it reduces the formation of vortices by the dimples and hence heat transfer reduces.

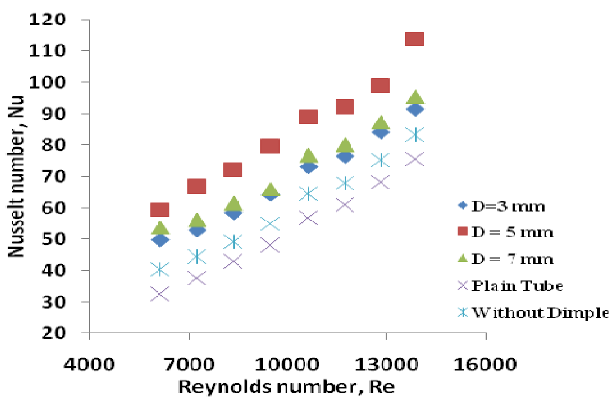


Figure 6: Variation of Nusselt Number with Reynolds Number for Twisted Tape with Different Dimple Diameter and its Comparison with Plain Tube and Twisted Tape without Dimple.

4.3 Effect of Dimple Diameter on Friction Factor

Deviation of friction variable with Re from the plain tube, twisted tape without dimples and twisted tape along with dimples (D=3mm, 5mm and 7mm) are given in figure 7, in which the consequences of dimple diameter onto friction immunity are considered. It may be observed that in most scenarios, friction factor is inversely proportional to the Reynolds number. Twisted tapes result greater friction variable in relation to the plain tube. Above the assortment of Re researched, friction variable at the tube paired with jagged tape with no dimple, jagged tape together with dimples of d = 3mm, 5mm and 7mm has been 3.34-3.63, respectively 3.62-4.36, 4.86-5.10 along with 5.76-6.06 times larger than plain tube. Friction factor also depends upon diameter of dimples and it's directly connected to this dimple diameter. Friction factor raises because of secondary circulation generated from the tape that is twisted, trapping impact created by the dimples and frictional resistance involving dimpled twisted surface along with the flowing fluid because dimple reduces the flow region and gives more contact layer.

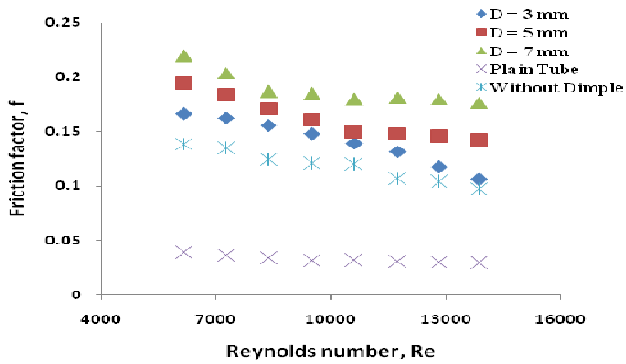


Figure 7: Difference of Friction Factor with Reynolds Number for Twisted Tape of Different Dimple Diameter and it is Compared to the Plain Tube and Twisted Tape without Dimple.

4.4 Effect of Dimple Diameter on Performance Evaluation Criteria (PEC)

Deviations of performance test standards (PEC) with Re from the tube without insert and also in tubes with jagged tapes insert been shown at Figure 8. It could be observed in the Figure 8 which the PEC reduced with increase in Reynolds number. It shows that when Reynolds number increases the impact of jagged tape, on friction variable gets increasingly more important with raising Re in test using Nu. On the investigated range of Re, PEC of twisted tape with no dimple is least among the rest of the structures; it indicates that in this scenario friction variable is considerably prevailing over heat transfer. PEC of jagged tape with dimples of D =3mm, 5mm and 7mm are 1.15-1.23, 1.27-1.40 and 1.04-1.17 times greater than the PEC of tube fitted with twisted tape without dimple.

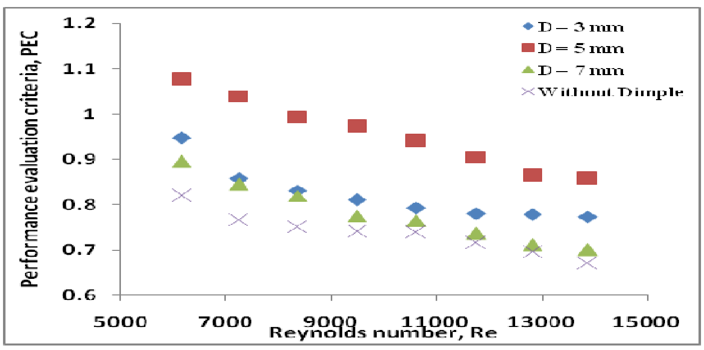


Figure 8: Variation of PEC with Reynolds Number for Twisted Tape with Different Dimple Diameter and its Comparison with Twisted Tape without Dimple.

5. CONCLUSIONS

The effect of jagged tape inserts along with dimple of another diameter on heat transformation and friction factor characteristics is studied with experiment. The conclusions also are resulted as follow:

Over a range of Reynolds number investigated jagged tape inserts with dimples gives larger Nusselt number and friction factor when compared to twisted tape inserts without dimple and plain tube. The Nusselt number rises as diameter of dimple increases from 3mm to 5mm and then decreases as diameter increases from 5mm to 7mm. This is due to some flow that is trapped at the bottom of the dimple and flow is separated by the protrusion. Friction factor depends on diameter of dimple and it is directly proportional to the diameter of dimple. It is because dimple~~s~~ decreases the flow area and provides more contact surface. As the Reynolds number increases the effect of jagged tape with dimples on friction factor becomes more significant with rising Re when compared to Nu. Over the range of Reynolds number investigated, PEC of jagged tape without dimple is least among all other arrangements, it means in this case friction factor is predominant over Nusselt number.

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